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THE TEACHING OF THE HISTORY OF SCIENCE

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DURING the last two years I have had to lecture on the history of science before a score of American and Canadian universities. In each university center I have naturally met and discussed with most of the people interested in the subject, which has enabled me to gauge pretty accurately the general sentiment concerning it and to figure the prospects of these studies. The present essay is the fruit not simply of this random experience as a lecturer, but also of my experience as a teacher in Harvard, Columbia, at the University of Illinois and the George Washington University. I propose both to clear up some misunderstandings, the further development of which might be more fatal to the history of science than mere indifference, and to answer a question which has often been addressed to me:

> You always lay stress on the importance of the history of science, as the best way of *humanizing* science and giving to it its whole educational value. But how shall we best do it? How should these studies be organized? And what should be the spirit of this teaching? . . .

The main misunderstanding to be dispelled (I will return to it, but I wish the reader to know from the start where I am aiming) is one which is chiefly bred by professors of philosophy. I have had the privilege to talk with many of these after my lectures, and not a few seemed to be surprised at my statement that the history of science had yet hardly been taught. Why! they themselves had been teaching it in their courses on the history of philosophy. . . . They spoke of Thales, Pythagoras, Democrites . . . they had actually explained the development of ideas on atomism, heredity, cosmic evolution, etc. . . . What more did I want?—Well, I wanted so much more and I felt that they were so deeply ignorant of the most elementary facts of science, so unaware of their real significance, so innocent of the true spirit of science, that I often gave up explaining anything. But I became more and more convinced of the necessity of insisting above everything else on the scientific foundation of the history of science. The chief requisite for the making of a good chicken pie is chicken; nay, no amount of culinary legerdemain can make up for the lack of chicken. In the same way, the chief requisite for the history of science is intimate scientific knowledge; no amount of philosophic legerdemain can make up for its absence.

THE TEACHING MUST BE EXPERIMENTAL AND CONCRETE

> The purpose of the history of science is to establish the genesis and the development of scientific facts and ideas, taking into account all intellectual exchanges and all influences brought into play by the very progress of civilization. It is indeed a history of civilization considered from its highest point of view. The center of interest is the evolution of science, but general history remains always in the background.[1]

Of course, it is the natural, chronological development that we must especially consider, not the deductive and artificial. One of the petty ideas of philosophers is to elaborate a classification, a hierarchy of sciences. They all try it, and they are generally so fond of their favorite scheme that they are prone to attach an absurd importance to it. We must not let ourselves be misled by this. Classifications are always artificial; none more than this, however. There is nothing of value to get out of a classification of science; it dissembles more beauty and order than it can possibly reveal.

As a matter of fact, the most fascinating part of science is the intimate and intricate relations it possesses, not with fanciful doctrines, but with life itself. We can safely say that each new scientific development is due to the pressure of some social need. Of course, we include amongst these needs the insatiable curiosity of certain men, because even this curiosity, disinterested and inopportune as it may seem, is still nothing but a response either to an old problem of nature, or to one arising from new social circumstances. Even the development of mathematics is largely a natural, not a purely logical one: mathematicians are continually answering questions suggested by astronomers or physicists; many essential mathematical theories are but the reflex outgrowth from physical puzzles.

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[1] G. Sarton in *The Monist,* XXVI., p. 333, 1916.

Further, the development of science is to a great extent impersonal. It is not the man of genius who leads it—he is only the "star" of the play—the real causes of this development are far deeper and as much beyond our ken as the sources of organic evolution. The different phyla of animals and plants did not successively appear according to a beautiful scheme of gradually increasing complexity; they are all evolving together because they all depend one upon another in many ways. At any stage of development there are all kinds of organisms—some very simple, some very complex—but it can not be said that the latter are more perfect because they all are the solutions of intrinsically different problems. The simplest are apparently as well adapted to their own conditions as the most complex. In the same way all sciences grow together, helping and stimulating one another, with little if any regard for logic and hierarchy; their growth is simply a function of their inner vitality and of the various needs of life.

The development of science is an organic development. We must study and teach it as such and not otherwise. Our teaching must be as unphilosophical and as unscholastic as possible. The few serious courses that have been thus far devoted to these studies, here and abroad, have been, with the possible exception of Mach's lectures, far too philosophical, I mean—far too prone to premature generalizations. In the case of France, this is due to the influence of Auguste Comte and more generally to the French love of system. In the English-speaking world, the influence of the positivist school has been working in the same direction. More recently the very learned and massive publications of John Theodore Merz have accentuated this ratiocinating tendency in the most disastrous way. His "History of European Thought in the Nineteenth Century," enjoying as it does a kind of monopoly, is unanimously praised, especially by those who would make us believe that they have read it. This book certainly conceals a considerable amount of material, but it is so prolix and discursive that its rich substance has to be almost entirely redigested to be of any great service.

Abstract as it is, science is but an outgrowth of life. That is what the teacher must continually keep in mind. If he seeks his inspiration in any philosophical system instead of letting himself be guided by the plain realities of scientific development, he may produce books that will interest philosophers, but he is lost as a historian. On the contrary, let him follow the lead that I am giving. Let him explain the development of science, as of something living and growing like an animal or a plant, answering to the stimuli of its environment; let him show that each problem of life releases a new train of scientific problems, and that all these trains interfere one with another and continually give birth to new discoveries and arrangements —and he will soon give to the student the feeling that science is not a dead system—the excretion of a monstrous pedantism —but really one of the most vigorous and exuberant phases of human life. Science has always been growing and changing as it does even now. The teacher must continually strive to increase the intimacy of his disciples with this rich inner life of science. Of course, this will only be possible if he be himself on intimate terms with it. But if he succeed in doing this, his teaching will certainly prove interesting and stimulating.

These are the two alternatives: either the course on the history of science will sooner or later degenerate into a new course of philosophy, and its generality and simplicity will give the student a false sense of knowledge, or it will be, as I say, experimental, concrete, matter of fact.

I do not say that generalizations must be avoided, but simply that they must be reduced to a safe minimum and only offered to the student when all the facts of the case are well understood by him.

These facts are of two different kinds: historical and scientific. The teaching of the history of science must be essentially the interpretation of these two sets of facts. Let us now consider how better to explain each of them and how to harmonize the simultaneous teaching of both.

THE TEACHING OF HISTORICAL FACTS

It is in the historical part of the teaching that the connections between science and all other human activities are made manifest. Hence this part is the most important from the pure humanistic point of view. The basis of any historical interpretation, of course, is the arrangement of all interesting facts in a chronological sequence. This implies painstaking and monotonous research work, a drudgery from which most scientists would fain escape. But this work being fundamental can not be too accurately done, even in those cases where historical details may seem of trivial importance. Accuracy is to the scholar what discipline is to the soldier: it must be implicit or it is not worth anything.

I have already shown elsewhere that the development of science is intimately connected with every other human development; there are continuous interactions, for example, between science and art, science and religion, science and industry, science and law, . . . not to speak of the influences revealed by general or political history. It is the historian's business to disclose these various and continuous interactions, and so to bring into greater relief the organic development of science. He will show that this development is really the culmination of human achievement. He will lay particular stress on the relations of this greatest of human tasks with two others which are almost as important; the creation of beauty and the development of social institutions.[2] Indeed, it should be obvious to all that it is these developments, but chiefly the development of knowledge, upon which the history of human progress should be focused. To make this clear, the teacher will lose no opportunity of showing the cumulative and progressive, also the international character which is specific to science.

The center of gravity of historical studies must be displaced. As a matter of fact it has been moving all along in the direction which I indicate: at first it was dynastic, then military, national, political, institutional, social . . . it is now high time that it become really scientific. Human achievement in the realms of knowledge, beauty and justice is the real thing; the rest is merely anecdotic. Of course, most historians can not be expected to subscribe to this, and many will imperturbably follow their own lines without even trying to know something of the evolution of science. There is no objection to that, any more than there can be any to the simultaneous existence and to the collaboration of organisms having reached different stages of development. Protozoa, insects, birds and men . . . each is doing his little bit. The only thing which will have to be stopped is the old historian's belief that his medieval point of view is really the most catholic; also his absurd pretense to control historical studies.

It is well to give due importance to the biographical side. There is no better way of stimulating the student's interest than to narrate with sufficient detail the lives of those heroes to whose efforts and sacrifices we owe the best of our civilization. And if they really had to suffer because they were so much ahead of their time, and too little concerned with the requisites of every-day life, if they were not understood and died unrewarded, it becomes the historian's sacred duty to redress this injustice by explaining in full the greatness of their work, and making them live again, forever.

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[2] However important and impressive these two developments may be, they are not just as important as the development of science because they are less specifically human. Some animal societies have reached a high stage of perfection; it may be that it is less the lack of solidarity than the lack of positive knowledge, of tools, that has prevented them from going even higher. As to beauty, there is an infinite amount of it outside of man.

THE TEACHING OF SCIENTIFIC FACTS

Important as it is, the historical side of our studies must evidently be subordinated to the scientific side. There would be little sense in explaining the history of something which would not in itself be clearly understood.

And yet this is perhaps the weakest point of most courses on the history of science, and one can not help shivering at the thought of what would happen if such courses fell into the hands of scientifically untrained philosophers. It is a well-known fact that people having no direct knowledge of science are almost bound to make fatal mistakes on essential points, often on those which appear to be extremely simple.

Now, if a course on the history of science were to become the vehicle of false or inaccurate scientific ideas, it would be more detrimental than useful. Hence the professor of general history should forbear from dealing with scientific facts of which he is not able to give an accurate and circumstantial account. As to the instructor on the history of science, he should not undertake to tell the history of any scientific idea, without making sure of his ability to explain the full signification not only of this idea, but also of each step which led to its discovery. He must be able to do this in the most concrete and specific way.

It follows from this that he should be given all the paraphernalia necessary for the explanation of the scientific facts involved, such as maps, charts, pictures, models and various apparatus. How can it be possible to interpret—say—Galen's or Vesalius's anatomical discoveries (also their mistakes) or the discovery of the circulation of the blood or of the nervous function, without having at least some good anatomical models or drawings upon which to point out the various details alluded to? With the proper models the teaching is easy, clear, convincing, interesting; it becomes hopelessly dry, confusing and tiresome without them. It is noteworthy that these models and charts are necessary both for introductory and for the most special courses. In the case of elementary courses, however, they are especially useful in the avoidance of too many technical terms. I have borrowed my examples from the field of biology, but the same thing is true of any other department of science. How shall I properly explain the development as well of primitive tools, as of the steam engine or the dynamo—without models or pictures? of geographical discoveries, without maps? In the latter case, maps are not even sufficient. When I narrate the discovery of America, I should like to be able to explain exactly how Columbus navigated. Therefore I should need a cross-staff, an astrolabe, a primitive compass, a portolano and some early printed astronomical table. It would not be necessary, of course, to have original instruments and copies could be easily obtained at a relatively low cost. Does not any one see that such teaching of the geographical discoveries would have infinitely more sense and import than the usual vague and literary description?—I know that the literary people will insinuate that I would destroy all the romance of these adventures. I do not believe in the romanticism of ignorance. What is truly heroic, pathetic, grand, would certainly be put in stronger relief by such explanations. If the early navigators had been blind fools, we could not call them heroes; they were conscious of their purpose and of the dangers to be encountered and they had to pool all their knowledge and energy to fight against nature. The literary people have told but a small part of their story.

Models and instruments would not be less needed for the teaching of more abstract sciences, even of mathematics. To elucidate the development of the latter, its cultural value and its relation to other sciences, it is well to be able to show ancient instruments—for example, abaci, arithmetical machines, slide rules—not to speak of geometrical models and of more complex mathematical machines which become almost indispensable. Will not a lecture on the work of Fourier, for example—either in a course on the history of mathematics or in one on the history of physics—gain considerably in interest if it be possible to demonstrate its further applications by means of some kind of harmonic analyzer?

It is not less necessary, whenever the subject lends itself to it, to make some fundamental experiments. It would be the more necessary if the students have less scientific training. It should not be permissible to speak of Galileo without making some very simple experiments on gravity, nor to speak of Huygens, without illustrating in a similar way the laws of centrifugal force. No amount of verbal explanation can ever replace such experiments. In a general course on the history of science, all the fundamental facts of physics, chemistry, biology, should be demonstrated experimentally whenever it is possible to do so without too much trouble. I may add that if it became a common practice to illustrate historical courses by experiments, a greater accuracy in the statement of scientific facts would be automatically secured.

The scientists teaching the history of their own science in their own lecture hall, if they are often handicapped by a serious lack of historical training, at least have the enormous advantage of being able to make the necessary experiments with greater ease and effectiveness. What such courses often lose in historical accuracy they gain in scientific precision and experimental pointedness.

I do not hesitate to say that without experiments the very best of these courses on the history of science is lost. The experiment is not simply necessary, as in a regular scientific course, to prove the fact to the student's senses. It is of even greater importance in our case, to introduce him to the handicraft part, the most living part, of science. This can hardly be explained with words. The student must be made to understand that science is not simply a product of the brain, but also of the whole of our muscular and sensual experience. To know a science does not mean simply to remember a certain number of facts and principles duly classified; it implies far more an intimate acquaintance with various methods and apparatus into which a great deal of scientific thought is so to say crystallized. Even in mathematics, there is room for a certain amount of handicraft of a subtler kind—the almost automatic handling of certain formulæ and symbols.

It is essential for the student to understand this to the best of his ability, because it is only on this condition that he will be able to watch the inner growth of science, and to see it, so to say, in the making. Great discoveries have been made chiefly by men whose entire attention was concentrated upon limited problems and specific experiments, then upon certain material details of these experiments. That is the real heart of science; the spring of its eternal youth.

Any philosophical or literary history of science necessarily fails, and will ever fail, to show that. As a matter of fact, no history of science has ever been written from this point of view —none that I know of, not even Ernst Mach's admirable history of mechanics, although he has come considerably nearer to this ideal than any other author.

EQUIPMENT

Lectures on the history of science illustrated by experiments and various demonstrations can not possibly be given in an ordinary lecture hall. There are three methods of solving this practical difficulty.

The first is to have the lectures delivered in the various scientific halls where the needed implements would be at hand.

Lectures pertaining to anatomy might be given in the medical school; lectures on Galileo, Newton or Helmholtz in the physics building, and so forth. This method would be the source of so many conflicts and misunderstandings, even if the different halls were sufficiently near to each other, that we may just as well dismiss it as impracticable.

There remain the two other solutions: the ideal one is to provide for this teaching a special lecture room, completely equipped for the making of simple physical, chemical and biological experiments. If this was found to be too expensive, the historical courses could be given in any other scientific hall. The instructor would then deliver most of his lectures in this hall, but would have to take his flock to other halls whenever necessary. It must be noted that even if a well-equipped hall were placed at the lecturer's disposal, he might still find it necessary to give once in a while a lecture in another building, in the observatory, for instance, or in one of the university museums.

It is not necessary here to describe the ideal lecture hall which I have in mind; it would simply combine the main features of ordinary physical, chemical and biological amphitheaters. The chief difference between my lecture hall and these amphitheaters would lie less in the hall itself than in the series of instruments and models collected either around it or in neighboring rooms. There should be sets of geographical and historical maps; also anatomical, zoological, botanical, geological . . . charts and models. In short, the instructor should be enabled to fully interpret each scientific fact to which he would refer. A collection of portraits of the great scientists would also be desirable, but this is less essential. It would be necessary to have a good set of copies of primitive and ancient instruments: early types of armillary and celestial spheres, microscopes, telescopes, celestial machines, alembics, surgical and obstetrical instruments. . . . Most of these early instruments being rather simple, the making of copies would not be very expensive; it would certainly be far less expensive than most of the models or specimens used in the teaching of biology and natural history. Many antiquated instruments might likely be found in the collection rooms (if not in the attics!) of the scientific buildings of the oldest universities, and, I surmise, would gladly be given or lent to the new department for further and better use.

I must limit myself here to these general indications, but I propose to publish subsequently a more detailed description of the lecture hall with a tentative list of the maps, charts, models and instruments which would be most urgently needed.

PREVIOUS WORK IN THE SAME DIRECTION

I do not know of any general course on the history of science, anywhere, which is conducted along the lines which I have indicated. Most of the courses of which I know are to a large extent philosophical courses and lack both historical and scientific concreteness and accuracy.

But something nearer to what I have in mind *may* have been done in the teaching of the history of special branches of science, especially medicine. Courses on the history of medicine have been delivered in many European and American universities, generally by one of the professors of the medical school speaking in his own auditorium with plenty of illustrative material close at hand. In this case, however, there is little opportunity for experiments, except on the occasion of some physiological digression. I must also refer to the little mathematical museum which Dr. D. E. Smith has organized in Teachers College, Columbia University, close to his lecture room. Almost all the objects exhibited are original implements wherewith to illustrate the development of mathematics, not simply in Europe, but also in India, China and Japan. Dr. Smith uses extensively his treasures in his lectures on the history of mathematics, and it was my own privilege, thanks to his courtesy, to be able to use them too when I lectured at Columbia in the summer of 1917. This strengthened my belief that there is no better way of impressing upon the student's mind the relations of abstract mathematics to reality.

As to the physical and biological sciences, for the historical interpretation of which so much illustrative material and so many experiments would be needed, I do not know of any course in which such demonstrations have been actually carried out. The reader will surely think of Ernst Mach, who was professor of inductive philosophy at the University of Vienna from 1895 to 1901. I have no definite information about his method of teaching; I do not know to what extent his courses were experimental. But as Mach had become more and more interested in psychological rather than historical research, it is likely that his teaching was very different from the one of which I am thinking.

GENERAL SCIENCE

The development of science has become so multitudinous and luxuriant in the nineteenth century, still more in the twentieth;

its complexity, the wealth of facts garnered all over the world, is increasing at such a terrific rate that it is no longer possible to contribute much to its progress unless one concentrates one's efforts and intelligence upon the exploration of a particular field. Every day the field which the average scientist may hope to till fructuously is becoming smaller, and thousands of men are doomed to spend their lives within a very restricted intellectual horizon. However necessary these human sacrifices may be for the advancement of science, they are nevertheless befraught with perils; nay, if they be not compensated in some way or another, they may endanger the whole fabric of civilization.

The only remedy is that which has already been applied in other departments of human activity, in the industrial realm for instance. There also have an increasing specialization and standardization become conditions of success. But business men, who never run the risk of losing touch with reality, have quickly grasped that if no corrective were brought to this extreme specialism, the loss due to disintegration would soon offset the gain in efficiency. Hence, they will no longer allow the creation of new departments or specialties without providing at the same time for some kind of coordinating agency. In the same way, the more most scientists become intensely specialized, the more urgent it is that at least a few devote themselves exclusively to the coordination and synthesis of the whole work. This new specialty, that is the study of general science, is the only means of avoiding the disintegration of the whole and the impoverishment of the scientific spirit.

This study, which many scientists would hardly dare approach, is not necessarily more difficult than any other special study; it is different; it requires a different training, that is all. The men devoting themselves to it would be able to stand in stead of the specialists, to guide them outside of their own garden, to prepare comprehensive surveys, but what is even more important, they would be able to teach the young before they specialize and to give them a broad and solid scientific basis, which would later enable them to keep in touch with the rest of the creative work of the world, and to escape from their prison whenever they would wish to. This teaching would remain an inspiration to them throughout their life.

How should we organize this synthetic teaching? The most natural method is certainly the historical one. However specialized and distant the various ramifications of science may now be, they have all originated from the same trunk. All sciences have grown together, the progress of each promoting the others and releasing, so to say, new series of thought and inventions all around. To disentangle the apparently overwhelming intricacy of modern science, it is enough to study its heredity.

A concrete, experimental course on the history of science is the best imaginable course of general science, the best introduction to more advanced and special scientific research.

This seems clear enough, but I can not leave the subject of general science without dispelling a grave misunderstanding which obtains in many parts of this country. It is due to the fact that the words "general science" are frequently used with a different connotation from the one which I give to them. What I mean by them is the general fabric of science, the cardinal facts and ideas of each science, and chiefly their interrelations, their points of contact, their relative degree of perfection, the light they throw upon each other, also the view of the universe which is the result of their combined advance. Now I have here before me a very remarkable text-book edited by Frederic D. Barber.[3] It contains an extraordinary amount of information, clearly and simply presented, about most scientific problems which his environment might suggest to any intelligent youngster. The authors have a perfect right to call this book "a first course in general science," inasmuch as it is not dealing simply with physics, chemistry or biology, but with all these branches of science. Yet it is clear that "general science" is here given a very different meaning from my own. It is general science to be sure, but *everyday* science, not *fundamental* science.

The two points of view are radically distinct: the former is practical, utilitarian; the other is theoretical, esthetical, idealistic. From the point of view of everyday science, for instance, it is very important to have sufficient knowledge of the mechanism of an internal combustion engine to be able to handle it without danger or waste, but one may be very familiar with such an engine and yet not know the principles of thermodynamics. On the contrary, from a historical and philosophical point of view it is the knowledge of these principles which is supreme. So also, for him whose material needs must be satisfied as quickly as possible, it is essential to obtain from the beginning some rudimentary knowledge of the functions of his own body; but for one who has time to make his survey of nature in a more leisurely way, it is wiser to grasp first the fundamental principles of physiology and of course it will be easier to lay them bare in the simplest organisms than in such a highly differentiated structure as the human body.

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[3] "First Course in General Science," by F. D. Barber, M. L. Fuller, J. L. Pricer and H. W. Adams. New York, Henry Holt, 1917.

I do not mean to disparage the utilitarian conception of "general science." I am entirely in sympathy with the idea of diffusing clear information on the scientific substrata of everyday life. But neither can it be validly objected to me that courses in general science, such as I propose to establish, already exist, because the courses so-called answer a purpose altogether different from mine. It would be regrettable that such confusion were allowed to persist, and hence I would suggest to call the courses which I have in mind courses on the history of science—a well-grounded designation inasmuch as the method of approach would be essentially historical.

The teaching of the history of science is exposed to two chief dangers each equally to be avoided. The philosophic danger, that is, premature abstraction and generalization, and the utilitarian danger, that is, premature application. Both imply in different ways a serious lack of accuracy; but besides, the former entails a lack of contact with reality, a lack of life. The latter implies a misconception of the essentials of science, a lack of appreciation of its disinterested spirit and of its serene beauty. If the former evil were not sufficiently eschewed, the teaching would be of very little use; on the contrary, if it were too utilitarian, it would have no real educational value.

TYPICAL PROGRAM

How then should these courses on the history of science be organized in a large university? I consider that it would be in general sufficient to offer three courses each year. First an introductory course on the history of science throughout the ages. The outline of this course could not vary considerably from one year to another. Secondly, two special courses of which one would be devoted to the history of a special science: physics, chemistry, astronomy, biology . . . and the other to the history of science and civilization at a special period. The latter course would simply be an anticipation of what all courses on general history will be when the literary supremacy passes, a history of civilization focused upon the development of knowledge and social institutions. These special courses should be changed every year, so that students especially interested in them could achieve complete studies in a cycle of three or four years.[4]

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[4] The nearest approach to this was made in Harvard. Dr. L. J. Henderson has given there since 1911 a most stimulating course on the history of science. To this general course, I myself added from 1916 to 1918, four

To deliver these three series of lectures, and possibly to direct the activities of a seminary and the research work of advanced students, at least two instructors would be needed. Of both, at least the one in charge of the two special courses should be a specialist, having no other duty than to know and teach his subject as well as possible. His task would still be considerable, as there remains a considerable amount of pioneer work to be done. The writing of a text-book on the history of most sciences is still very much of a venture. There are not yet pedigreed text-books, embodying the accumulated labor of many generations of scholars.

One might ask how far down the history of each science should be carried on. It is not possible to give a general answer to this question. For one thing, neither have the different sciences progressed at the same rate, nor are they equally esoteric; whereas it is out of the question to teach the history of mathematics in the nineteenth century except to advanced mathematical students, the most recent geographical discoveries can be explained almost to any educated person, and nineteenth-century physics or chemistry, to any student having taken only one elaborate encyclopedic course on these branches. The special training of the instructor should also be considered. I assume that he has had a serious scientific training (both theoretical and experimental), but this training may have been chiefly physical, or chemical, or biological. He should be expected to teach the nineteenth-century history of the sciences which he best knows, not of the others.

It is noteworthy that the teaching of the history of modern science is anyhow of a nature very different from the teaching of ancient science. For the latter the main difficulties are historical; for the former, especially when it comes to nineteenth- and twentieth-century science, they rather lie in the statement of the scientific facts themselves. The original documents of nineteenth-century science are generally well known and easily accessible; most scientists have the greater part of them in the sets of periodicals of their laboratory. Hence, the teaching of the history of a branch of science in recent times could often be safely entrusted to a scientist cultivating this particular branch and having a sufficiently acute historical and philosophical sense. This will be even more true when good text-books on the development of nineteenth-century science will be available.

It would be expedient, however, to expect the regular professor of the history of science to devote once in a while a course

special courses. But facilities lacking, none of these five courses was experimental nor as concrete as it should have been.

of lectures to nineteenth-century science, in order to oblige him to keep in touch with living problems. This is essential to ensure the soundness of his teaching.

Local conditions also should be considered. For instance, a university in which the physical department is especially strong and draws a great number of students from all over the country should organize regular courses on the history of physics and induce the advanced students to attend them. In Belgium no one can obtain a doctor's degree in any science without having passed an examination on the history of this science. There is much wisdom in this, although I do not generally believe in examinations.

At least the student should be made to understand the necessity of attending such a course, not because he needs it from a purely material point of view, but because this would form an essential part of his educational background and would help him to appreciate the signification of his own work and its relations to the work of his fellowmen. It is not enough for him to become a clever physicist; he must become, to the limit of his propensities, a generous and broad-minded man. There are only two ways of shaking one's innate narrow-mindedness and provincialism: to move in space or to move in time. One is travel, the other history; both should be periodically resorted to.

CONCLUSIONS AND VARIOUS REMARKS

The history of science, to be of any service, must be constantly based on the safest and most complete historical and scientific knowledge. It then provides the most natural and most illuminating interpretation of general science. There is no better way of revealing its disinterested spirit and its supreme beauty; therefore no better way of giving to any scientific teaching its full educational value. A course on the history of science given by the right teacher at the right moment to the right student would constitute his supreme humanistic initiation.

It can not be too often repeated that the value of this teaching will largely depend upon the soundness of its scientific foundation. If it became too philosophic or literary, if it fell into the hands of people knowing science only in a superficial way, the result would inevitably be a falsification of science, with its logical sequences of misunderstandings and verbal quarrels. The course would then be really dangerous, as it would give the students a false illusion of knowledge. I insist that non-committal accuracy is not sufficient; the teaching must be precise and concrete; if not, the result would be neither science, nor literature, but a mongrel thing,—althogether bad. The chief purpose is to interpret the scientific spirit and methods: this can only be done by one having intimate acquaintance with the subject. Literary people and most philosophers are constitutionally unable to understand scientific methods and values. To entrust such courses to them would be to betray our ideal.

Neither should these courses be open without discrimination to any student. It must be kept in mind that the history of science can not be in itself a complete introduction to science. There is no short cut to scientific knowledge. The only way of attaining it is to study it systematically, with brain and hands. No student should be admitted before having successfully taken at least one laboratory course.

The more science they already know, the more would the students enjoy these lectures. They would supply to them the best recapitulation of the scientific facts and principles with which they would already be acquainted, from a novel and higher point of view.

Such historical courses should be considered, indeed, as a reward: the reward of the traveller who, having reached a stage of his long journey, looks down behind him along the slopes of the mountain upon which he has been climbing. The sun sets; his legs, his whole body, are tired but he thoroughly enjoys the well-deserved rest and the broad prospect which he has won. This is exceedingly sweet and cheering; truly, a great reward. . . .

The ultimate aim is to humanize science, and so to give to it its due part of the educational influence which has remained thus far by sheer inertia the monopoly of the so-called "humanities." Hence, the establishment of courses on the history of science, such as I understand them, will sooner or later entail an educational revolution. I have explained elsewhere, for instance, that it will oblige history to move its center of gravity. The history of civilization will be focused on what is most permanent, progressive and specifically human in the development of the race.

It will also procure the means of solving the old controversy "science *vs.* the humanities"—the modern visage of the ever-recurring contest between scholasticism and original and creative thought, the endless struggle between ever-rampant superstition and positive knowledge. The only cure of endemic scholasticism is experimental science.

We are not intolerant of the endeavors of the literary people, however; we love beauty, even the special form of beauty which they worship, as much as they do. Indeed, we have to thank art and literature for some of the greatest benedictions of life. But to value their treasures, it certainly can not be necessary to be ignorant of the laws of nature. It is impossible to see why a man should be less inspired or generous because he knows more. On the contrary, the better a man knows nature, the better will his heart vibrate at the touch of any true beauty. All other things remaining the same, his generosity, his inspiration will directly depend upon the amount and the quality of his knowledge.

The whole contest has been constantly obscured by the fact that it has been generally discussed and settled by literary people, impervious to scientific thought. How could they judge the relative merits of chemistry and Greek? What did they know of it? Yet they were the final judges. It is well known that most university presidents (and trustees) are literary people or lawyers. A generation or two ago they were chiefly theologians. But are literary people not just as unfit for intellectual leadership as theologians? They see only with one eye. The publications of the members of their scientific departments are just as unintelligible to them as if they were written in Chinese. How could these university presidents coordinate activities which they fail to understand? Their function becomes more and more a mere administrative one; they can not possibly be—what they should be—the inspirers, the spiritual guides of the faculty.

The whole thing becomes tragic when we realize that one of the most urgent tasks of our time, namely, to reconcile knowledge and idealism, is chiefly entrusted to them. We need both equally. I do not know which is worst, knowledge without idealism or idealism without knowledge, and yet our whole system of education is leading to their growing estrangement. It is clear that university presidents and trustees could do more than any other people towards the accomplishment of this task, if they were equal to it. In truth, a literary president is as hopeless as a blind admiral.

How long will it take to accomplish this educational revolution? I do not know. The struggle promises to last a considerable time. Think of the immense inertia incorporated in the present alliance of literary people, historians, philosophers; of the enormous weight added to it by the ignorance of the rulers, legislators, publicists, newswriters and of the great bulk of the teachers—all these men continually playing upon the religious and moral feelings of the people. Think of the united strength of tradition, superstition and ignorance. Moreover literary studies will always appeal more than any other to the mass, because they require less intellectual effort. Most people are very reluctant to use their brains; strange as it may seem, not a few find it easier to die than to think.

On the other hand, most scientists are so busy, so absorbed by their own research work, and—it grieves me to add—many have become so dull by dint of premature and extreme specialization that they do not try to get control of educational matters. They do not care any more; they are generally quite happy when a bone is thrown to them in the form of a new laboratory. Of course, business people now begin to understand that to equip a laboratory for physical or chemical, not to speak of medical, research is a sound investment. But how long will it last before they understand not simply the practical, the material value of science, but also its beauty, its greatness? Millionaires and city councils begin to appreciate art museums; but when will they see that there is also an infinite amount of unexplored beauty and fresh inspiration in the realm of science—and that it is high time to dig it out and to let more people, including the scientists themselves, partake of it?

No essential progress in the management of human affairs can be expected so long as the scientific methods and the scientific spirit are not more systematically applied to them. My own efforts are passionately bent on explaining that the brute knowledge of uneducated experts, precious as it may be from a purely material standpoint, would, notwithstanding, be a source of danger to our civilization. What is the use of being efficient, if we are to lose thereby all the joy, happiness and freedom which we need even more than bread? Yet, if we wish to survive, we must be efficient.

Idealism alone is blind and powerless; knowledge without compensation is brutal. We need the golden combination of both. To reconcile efficiency and happiness it is necessary and sufficient that science remain closely allied with beauty and charity. The establishment of this alliance is the whole program of the New Humanism.

SHORT BIBLIOGRAPHY

Two elementary text-books on the history of science have been published in America last year: Walter Libby's "Introduction to the History of Science" (Boston, Houghton Mifflin) and Sedgwick and Tyler's "Short History of Science" (New York, Macmillan). A more elaborate text-book —the best that we have thus far, however imperfect it may be—is Friedrich Dannemann's "Die Naturwissenschaften in ihrer Entwicklung und

in ihrem Zusammenhange," 4 vols., Leipzig, 1910.3. Aldo Mieli has begun the elaboration of a much vaster work, " Storia del pensiero scientifico dalle origini a tutto il secolo XVIII." One volume only has been published: " Le scuole ionica, pythagorica ed eleata," Firenze, 1916 (the author proposes to study the earlier periods later). Two other volumes are ready, but their publication is suspended on account of the war. Mieli is the most active representative of the New Humanism in Italy.

A splendid movement has been launched in Oxford by Dr. and Mrs. Charles Singer, Sir William Osler and others. They have just published the first volume of their " Studies in the History and Method of Science," Clarendon Press, 1917. This offensive is gallantly supported by F. S. Marvin, the author of " The Living Past " (Oxford, 1913), a little masterpiece of historical interpretation. Marvin has edited two other books: " The Unity of Western Civilization " and " Progress and History " (Oxford, 1915–6). See also his article on " Science and History " in *The Contemporary Review*, April, 1918.

Since I have quoted Marvin's work, I should also quote James Harvey Robinson's comprehensive and generous " Outline of the History of the Intellectual Class in Western Europe," New York, 1915, containing copious bibliographical information on the history of thought.

Ph. E. B. Jourdain has contributed many papers on the history and philosophy of science (chiefly mathematical) to *The Monist* (Chicago), of which he is one of the editors, and to the other reviews quoted below. Eugenio Rignano, editor of *Scientia*, international review of scientific synthesis (Bologna), and Sir Ronald Ross have done much also to promote these studies. It is invigorating to read Sir Ronald's caustic and spirited editorials in *Science Progress*, a quarterly review of scientific thought, work and affairs (London). A collection of Rignano's papers has just been translated into English: Essays in scientific synthesis, London, 1918. George Sarton, editor of *Isis*, revue internationale consacre â l'histoire de la science (Wondelgem, Belgium), has published many papers in his own review (1913–4), also in the *Revue générale des Sciences pures et appliquées*, Paris, 1912; in *The Monist*, July, 1915; in *Scientia*, 1918, and in *Science*, 1917 (An institute for the history of science and civilization, Vol. 45, p. 284.6; Vol. 46, p. 399–402). It is not a mere coincidence that each of the four last-named writers is, or was, the editor of a review devoted to scientific synthesis. Many other papers on the humanization of science have also been published in *Science*, New York, and still more in *Nature*, London.

For further bibliography, see Aksel G. Josephson, " Books on the History of Science," The John Crerar Library, Chicago, 1911; Supplement to December, 1916, *ibidem*, 1917.—Aldo Mieli, " La storia della scienza in Italia. Saggio di bibliografia di storia della scienza," Firenze, 1916.

Concerning teaching in the U. S., see Fred E. Brasch, " The Teaching of the History of Science. Its Present Status in Our Universities, Colleges and Technical Schools," *Science*, Vol. 42, p. 746–60, 1915. I would suggest that any new initiative in this field be communicated to F. E. Brasch, The John Crerar Library, Chicago, to enable him to keep the information up to date for the benefit of all concerned.

G. S.